SIEMENS

Slipstream Development & Testing of Post-Combustion CO_2 Capture and Separation Technology for Existing Coal-Fired Plants

DOE Contract DE-FE0003714

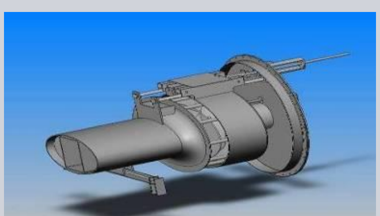
John L Winkler, Siemens

2.5 MWe Slipstream utilizing Siemens Amino Acid Salt (AAS) Solvent PostCap

NETL CO2 Capture Technology Meeting, August 23, 2011

Siemens Energy, Inc.
Environmental Systems & Services
Expanded Products for Global Markets

SIEMENS



- **Carbon Capture Technology (CC)**
  - Siemens PostCap Process
- **Flue Gas Desulfurization (FGD)**
  - Dry FGD
  - Mercury Control
  - Wet FGD
  - Wet ESP
- **Electrostatic Precipitators (ESP)**
  - HaRDE
  - VIGR
- **Fabric Filters (FF)**
  - Pulse Jet
  - Cartridge
  - Reverse Air
- **NO_X and Ancillary Products**
  - Low NO_X Burners
  - Overfire Air
  - SNCR/SCR
  - Boiler Design Upgrades

steinmüller engineering

Over 350 Systems & 115,000 MW of Utility Applications

Project Overview – Project Participants

- **DOE NETL – Project Sponsor / Awarding Agency**
- **Siemens Energy, Inc. – Technology, Equipment, and Installation provider. Co-Sponsor**
- **Tampa Electric Company – Proposed Host Site Provider, Big Bend Plant Units 1&2**

Project Objectives

- Demonstrate the ability of POSTCAP technology to achieve 90% CO_2 removal and approach a 35% increase of cost of electricity produced.
  - **AAS technology can reach 90% CO2 removal (already proven)**
  - **Challenge of approaching 35% increase in COE**
- Demonstrate the scalability and feasibility of progressing the POSTCAP technology to full-scale commercial application (550 MW) on post-combustion CO_2 capture for coal fired power plants and to full-scale commercial application for industrial sources of CO_2 emissions.
  - **Proving scalability**
  - **Proving feasibility**

Project Overview – Overall Project Performance Dates

Award, October 1, 2010

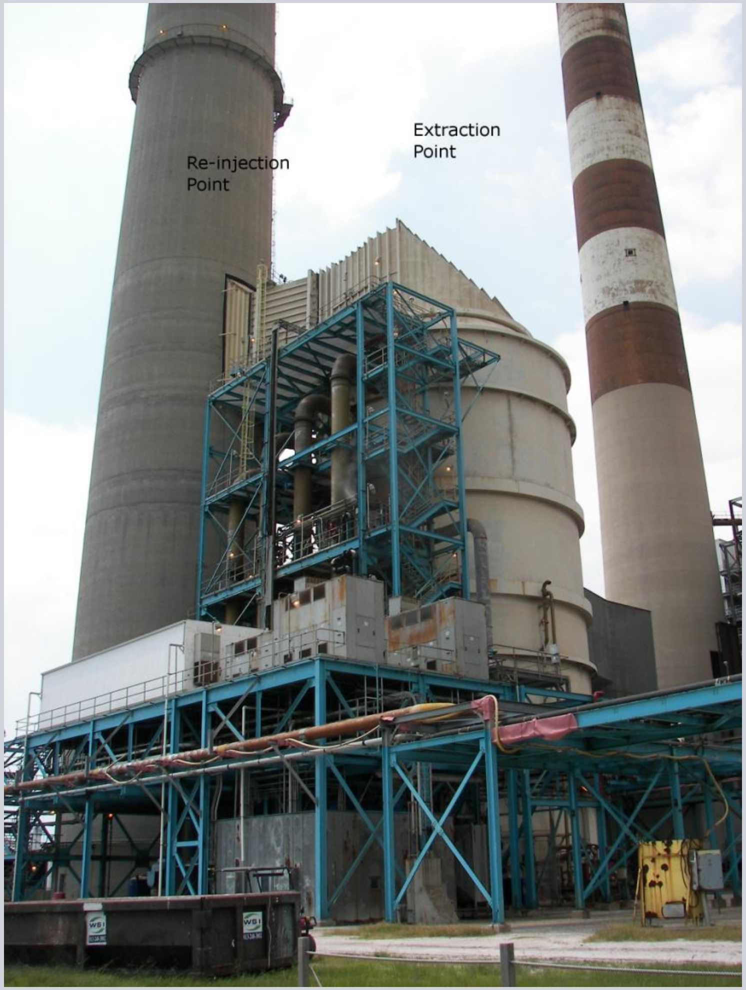
SIEMENS

Activity		
Kick-off	October 1, 2010	
Phase 1 – Process Design	October 1, 2010	October 31, 2011
Phase 2 – Procurement & Erection	October 31, 2011	Aug 31, 2012
Phase 3 – Operation & Testing	Sept 1, 2012	Jul 1, 2013
Issue Final Report (draft)		Jul 31, 2013

Project Scope

Slipstream Project Work

- Preliminary Engineering – Phase1
- Detailed Engineering & Design (three month extension) - Phase1
- Development of Equipment/Procurement Packages (three month extension) - Phase1
- Retrofit installation into existing Big Bend scrubber outlet – Phase2
- Commissioning, Operation and Testing of plant – Phase3
- Data Analysis, Report out – Phase3
- Decommissioning/Dismantling



Project Overview - Funding

	Budget Period 1 Process Design Oct 2010 – **Oct 2011**		Budget Period 2 Procurement & Erection Oct 2011 – Aug 2012		Budget Period 3 Operation & Testing Sep 2012 – Oct 2013	
	DOE share	Siemens share	DOE share	Siemens share	DOE share	Siemens share
Split (80/20) over 13 qtrs	$1,411 K	$353 K	$10,580 K	$2,645 K	$3,008 K	$752 K
DOE Project Share Total						**$15,000 K**
Siemens Project Share Total						**$ 3,750 K**

Status Report – Phase I, Detail Design and Engineering

SIEMENS

Challenges:

- significant underground obstructions found in the area of the proposed plant
- problems in developing steam supply for desorption column
- resulting engineering delays and inefficiencies

Result:

- Three month extension granted to Phase 1 portion of project schedule by DOE
- Additional costs incurred by Siemens for engineering

Project Milestones

Activity ID	Activity Name	(*)Early Start	(*)Early Fin	Actual Finish
PHASE 1				
SE0900	Task 1.0 Project Management and Planning	10/1/2010	7/31/2011	10/31/2011
SE1012	Task 2.0 Generation of Heat & Material Balance	10/1/2010	11/30/201	
SE1013	Task 3.0 Generation of PFD's	10/1/2010	11/30/201	
SE1014	Task 4.0 Plant Interface Engineering	10/1/2010	6/30/2011	
SE1015	Task 5.0 Preliminary Design	10/1/2010	2/28/2011	
SE1045	Task 6.0 Detail Design	3/1/2011	7/31/2011	10/31/2011

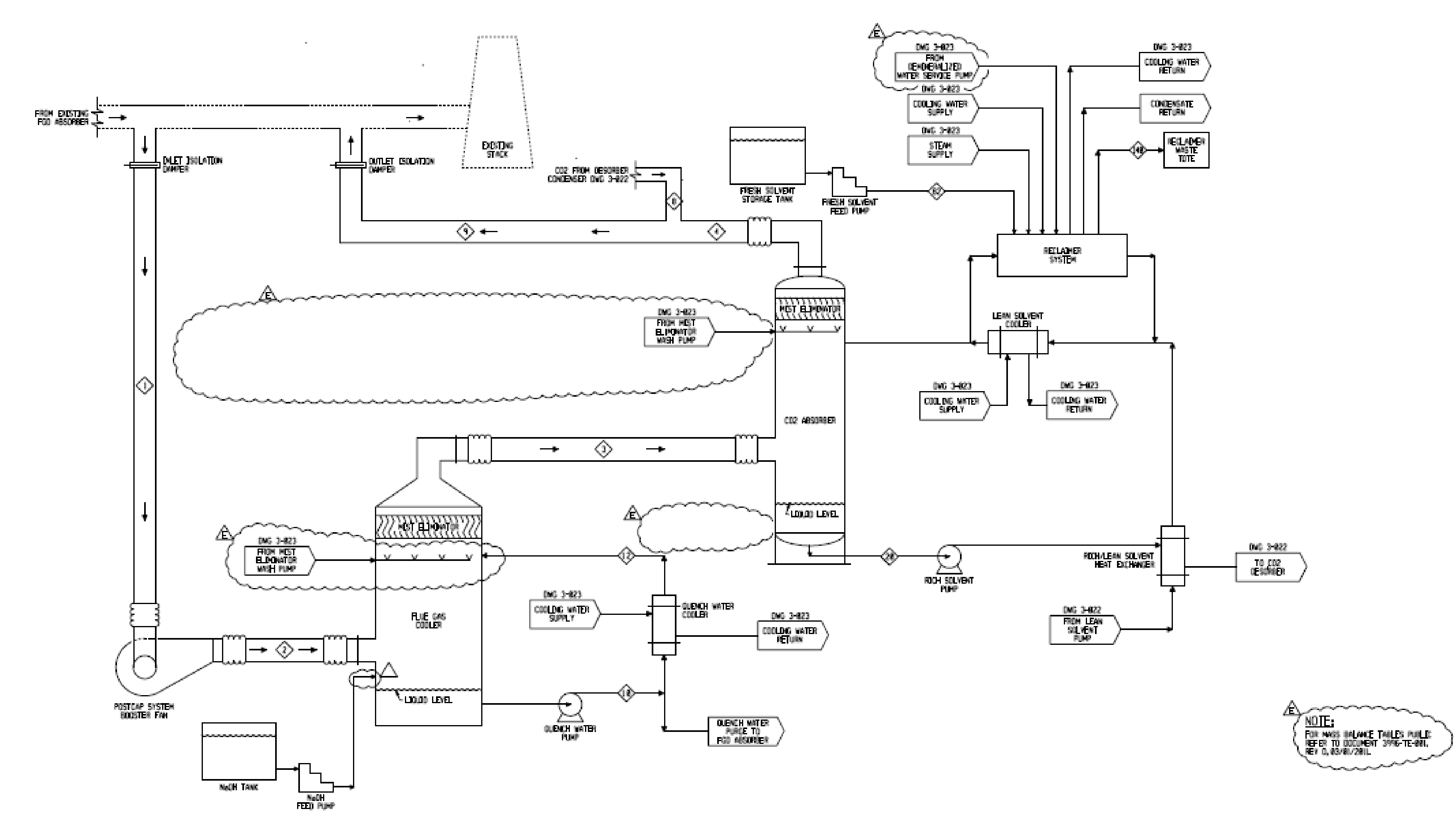
Project Methodology

Schedule

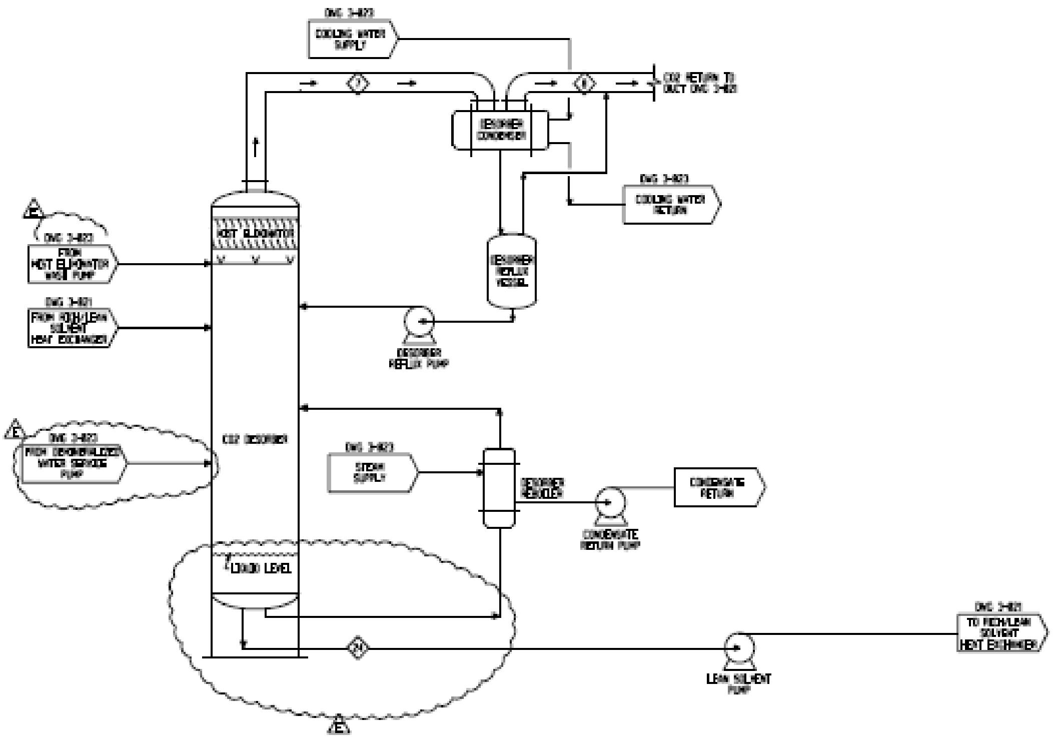
Task 1.0 Preliminary Design Engineering	10/1/2010	2/28/2011
Task 2.0 Generation of Heat & Material Balance	10/1/2010	11/30/2011
Task 3.0 Generation of PFD's	10/1/2010	11/30/2011
Task 4.0 Plant Interface Engineering	10/1/2010	6/30/2011
Task 5.0 Preliminary Design	10/1/2010	2/28/2011
Task 6.0 Detail Design/Engineering	3/1/2011	10/31/2011
Task 7.0 Site Civil Work	8/1/2011	11/31/2011
Task 8.0 Plant Equipment & Material Procurement	8/1/2011	8/30/2012
Task 9.0 Complete Erection of Structural Steel	9/1/2011	2/15/2012
Task 10.0 Absorber/Desorber Installation Complete	9/1/2011	5/9/2012
Task 11.0 Mechanical Installation Complete	9/1/2011	5/9/2012
Task 12.0 Piping Component Installation	12/1/2011	8/30/2012
Task 13.0 Complete Electrical Installation	2/1/2012	7/13/2012
Task 14.0 Complete I&C Installation	2/1/2012	8/30/2012
Task 15.0 Test Plan Development	6/1/2012	8/31/2012
Task 16.0 Phase 3 - Commissioning, Testing, and Reporting	9/1/2012	7/31/2013
Task 17.0 Perform System Hydro Test	9/1/2012	10/1/2012
Task 18.0 Perform Plant Startup	10/31/2012	12/3/2012
Task 19.0 Steady State Plant Operation	12/3/2012	7/1/2013
Task 20.0 Perform Testing	12/3/2012	7/1/2013
Task 21.0 Data Analysis	7/2/2013	7/31/2013
Task 22.0 Decommission	8/1/2013	10/31/2013
Task 23.0 Disassemble	8/1/2013	10/31/2013

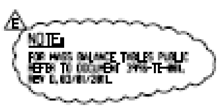
POST CAP PFD (1 of 2)

SIEMENS



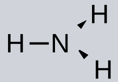
POST CAP PFD (2 of 2)



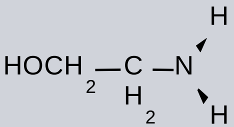


Technology Fundamentals – Amino Acid Salt is the basis of our solvent

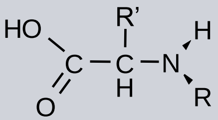
SIEMENS



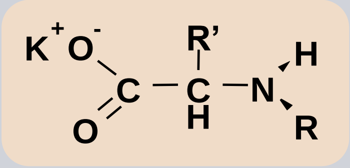
Ammonia



MEA



Amino acid



Amino acid salt

No vapor pressure

Chemically stable

Naturally present

Salts have no vapor pressure

- No thermodynamic solvent emissions
- Not flammable
- Not explosive
- Odorless
- No inhalation risk

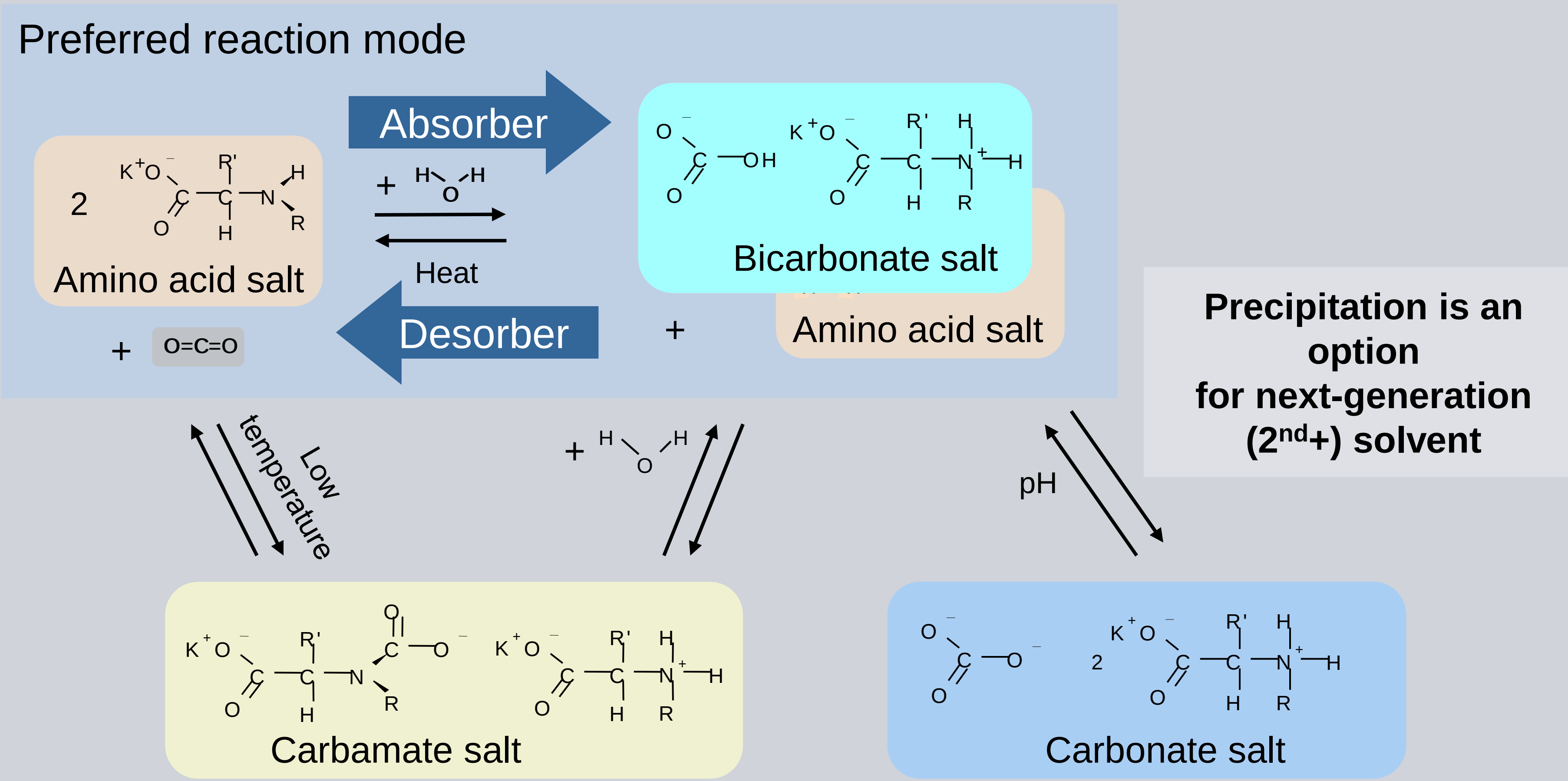
Negative ion is less sensitive to O_2

- Low degradation

Amino acids are naturally present

- Biodegradable
- Nontoxic
- Environmentally friendly

Technology Fundamentals



Intermediate reaction products fulfill the same HSE standard as amino acid salts

Technology Background - Solvent Stability and Current Performance

SIEMENS

Components	Amino Acid Salt w/o H_2O wash
VOC	not detectable
Formaldehyde	not detectable
Methylamine	not detectable
∑Nitrosamines	not detectable
Ammonia	<1 ppm

- the solvent is highly stable and does not lead to measurable loss of active substance due to degradation
- by-products in the liquid phase are salts with no vapor pressure
- No production of any mentionable amounts of emissions
- small amounts of heat stable salts (HSS) and nitrosamines will be removed with reclaimers

The amino-acid salt is stable against thermal stress and oxygen environments

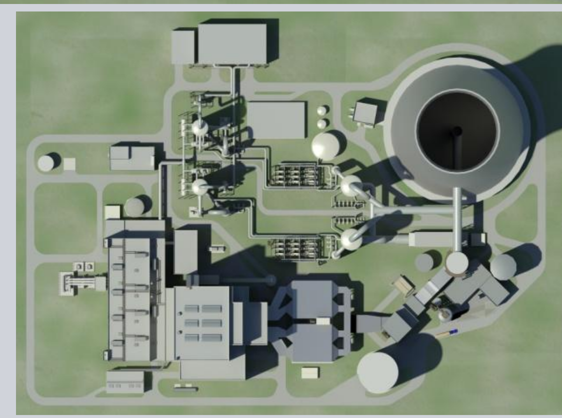
Background - Siemens lab plant for CO_2 capture tests at Frankfurt Hoechst Industrial Park

Background – E.ON Energie’s Staudinger 100 kW Pilot Plant

SIEMENS

Operational September 2009

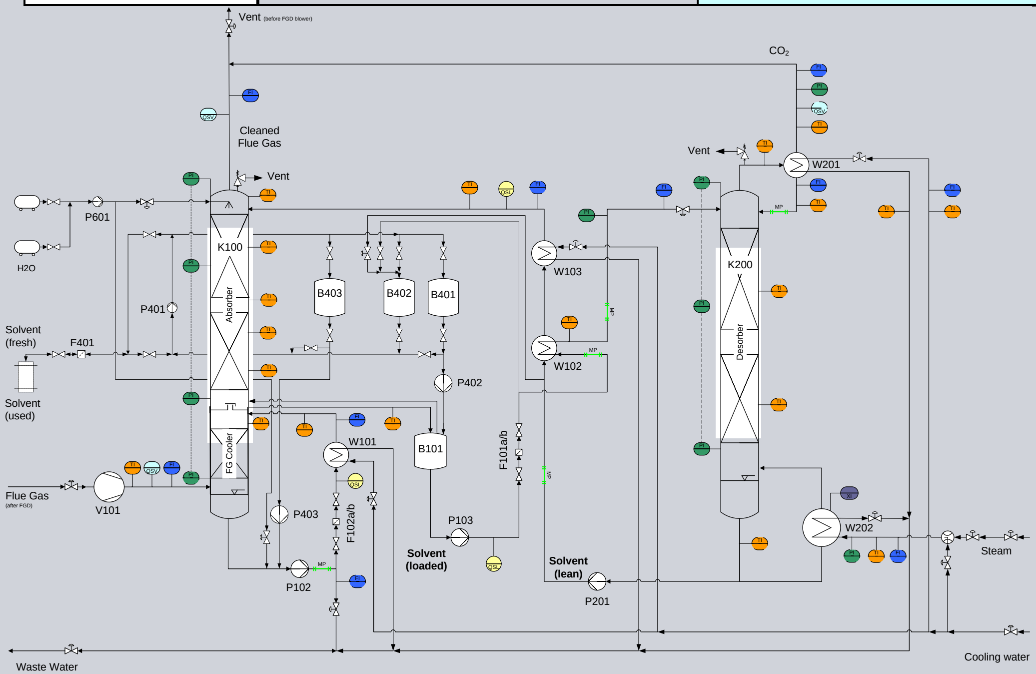
Upscaling via Slip-Stream Demoplants



Staudinger Pilot Test Program – 4,500 operating hours as of June 2011

SIEMENS

	2009					2010					
	Q3		Q4			Q1			Q2		
	August	September	October	November	December	January	February	March	April	May	June
Parameter optimization & Model confirmation	Functional tests with H_2O	Functional tests with solvent				Functional tests with solvent				Further tests	
Stability				Long term test run			Long term test run			Further tests	
Material				Material confirmation Proof of applicability of 1.4571					Material adaptation (Further screening of different materials)		



- Since the start up phase in August 2009 a large amount of test results have been collected
- Test results at different operating conditions were used to validate the existing process model
- Approx. 150 measurements were available to fit the model predictions to reality

Crystallization

SIEMENS

Absorption capacity		Crystallization behavior for different solvent concentrations
- A high CO_2 loading of the solvent was achieved - Various SO_x concentrations can be safely adjusted to investigate the behaviour of active AAS substance	↔	- Crystallization behaviour as a function of temperature and CO_2 loading was extensively studied and is well understood - Several process arrangements were made in order to prevent crystallization

Crystallization effects were safely avoided

Solvent Stability

SIEMENS

Results

Components	Amino Acid Salt w/o H_2O wash
VOC	not detectable
Formaldehyde	not detectable
Methylamine	not detectable
∑Nitrosamines	not detectable
Ammonia	<1 ppm

- the solvent is highly stable and does not lead to measurable loss of active substance due to degradation
- by-products in the liquid phase are salts with no vapor pressure
- No production of any mentionable amounts of emissions
- small amounts of heat stable salts (HSS) and nitrosamines will be removed with a reclaimer

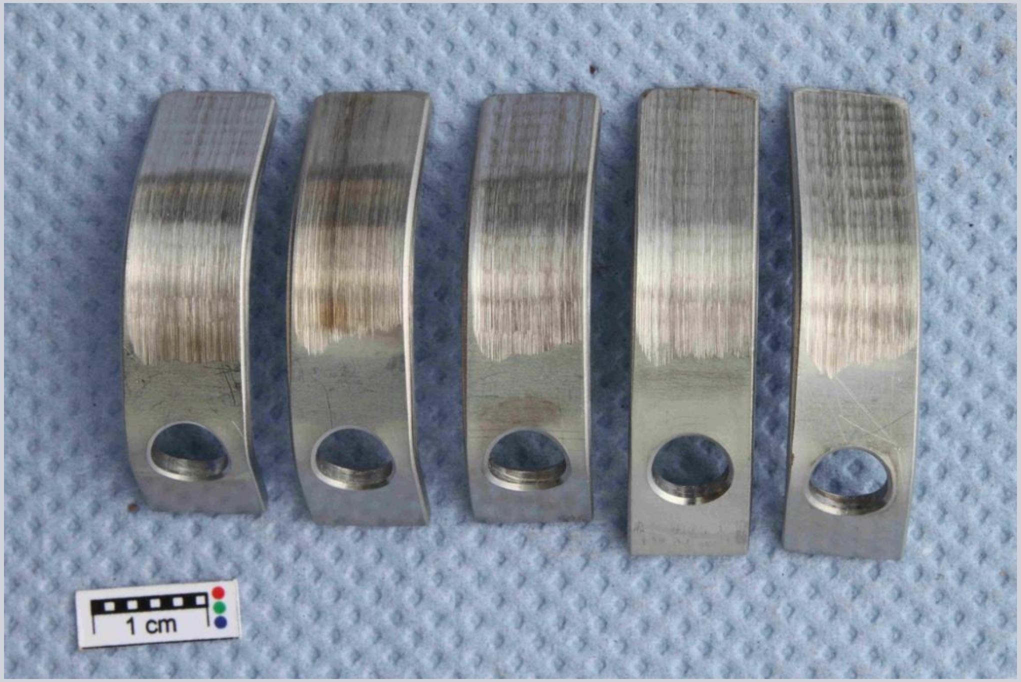
The amino-acid salt is stable against thermal stress and oxygen environments!

Corrosion Study

- Several Test Coupons (ST 1.4571*) were investigated from TÜV Süd according DIN 50905

- **No occurrence of local corrosion effects has been observed**

- Similar qualifications have been conducted for lower grade materials (carbon steel 1.0425, st 1.4541, st 1.4525) with generally good results



***st 1.4571 = EN X6CrNiMoTi17-12-2 or AISI/SAE 316 Ti**

Use of material stainless steel 1.4571 was confirmed, good potential for lower grade steels

Staudinger Pilot Plant Operation Results and Conclusions

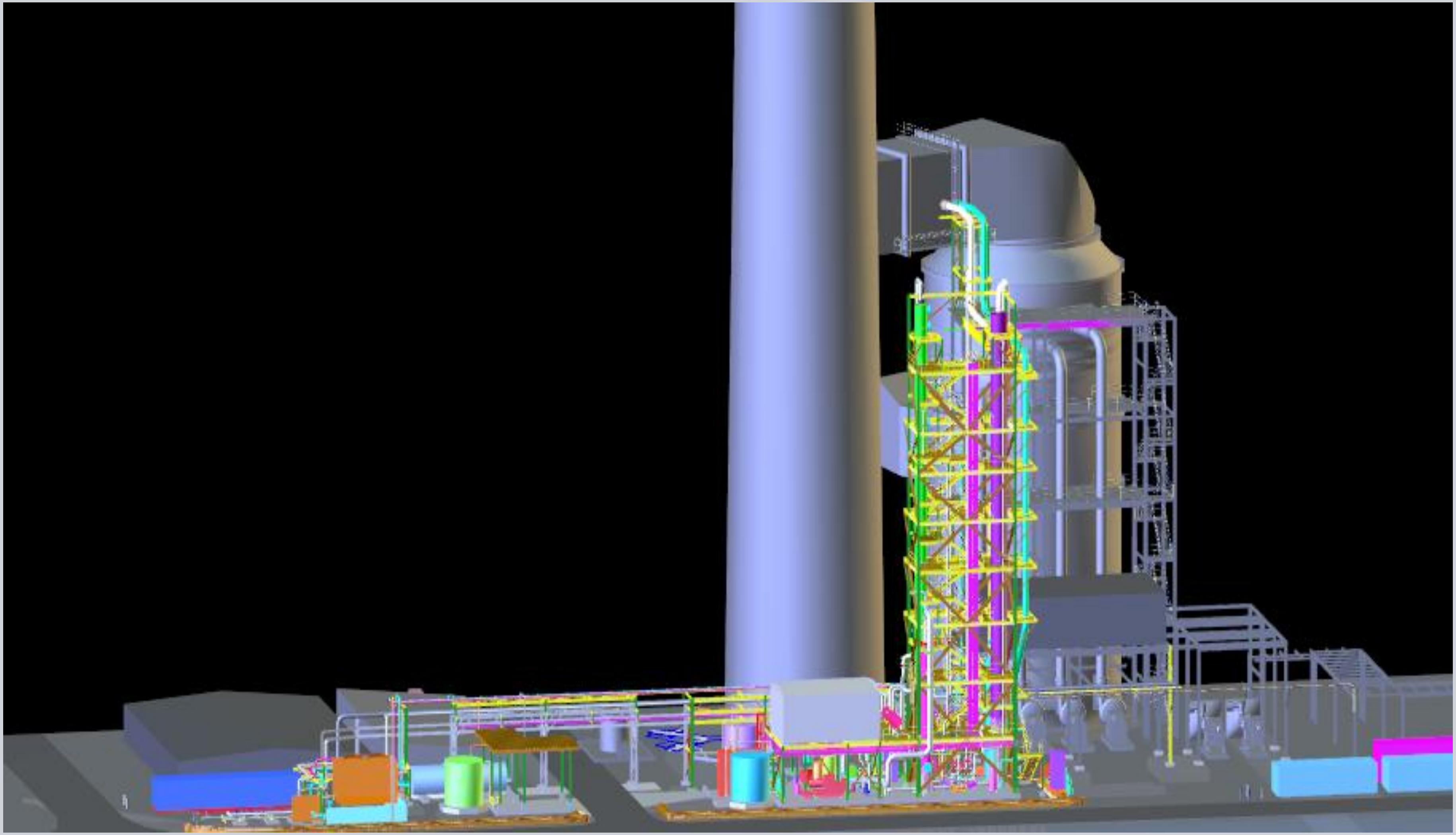
SIEMENS

Efficiency	Low energy consumption • < 6% pts efficiency loss • 2.7 GJ heat consumption High capture rate: >90 % proven	• EU prerequisites can be easily met • Low CO_2 capture cost
Emissions	• No predictable solvent and nitrosamine salt emissions	• Add'l washing step avoided • Permission less critical
Solvent stability	• < 1%/year solvent degradation by O_2 • High thermal stability • Smart reclaimer concept for SO_2 applicable	• Low refill requirements • Low reclaiming costs
Hardware	• Corrosion tests for construction material in all parts of capture plant	• Standard construction material applicable • Reduced investment costs

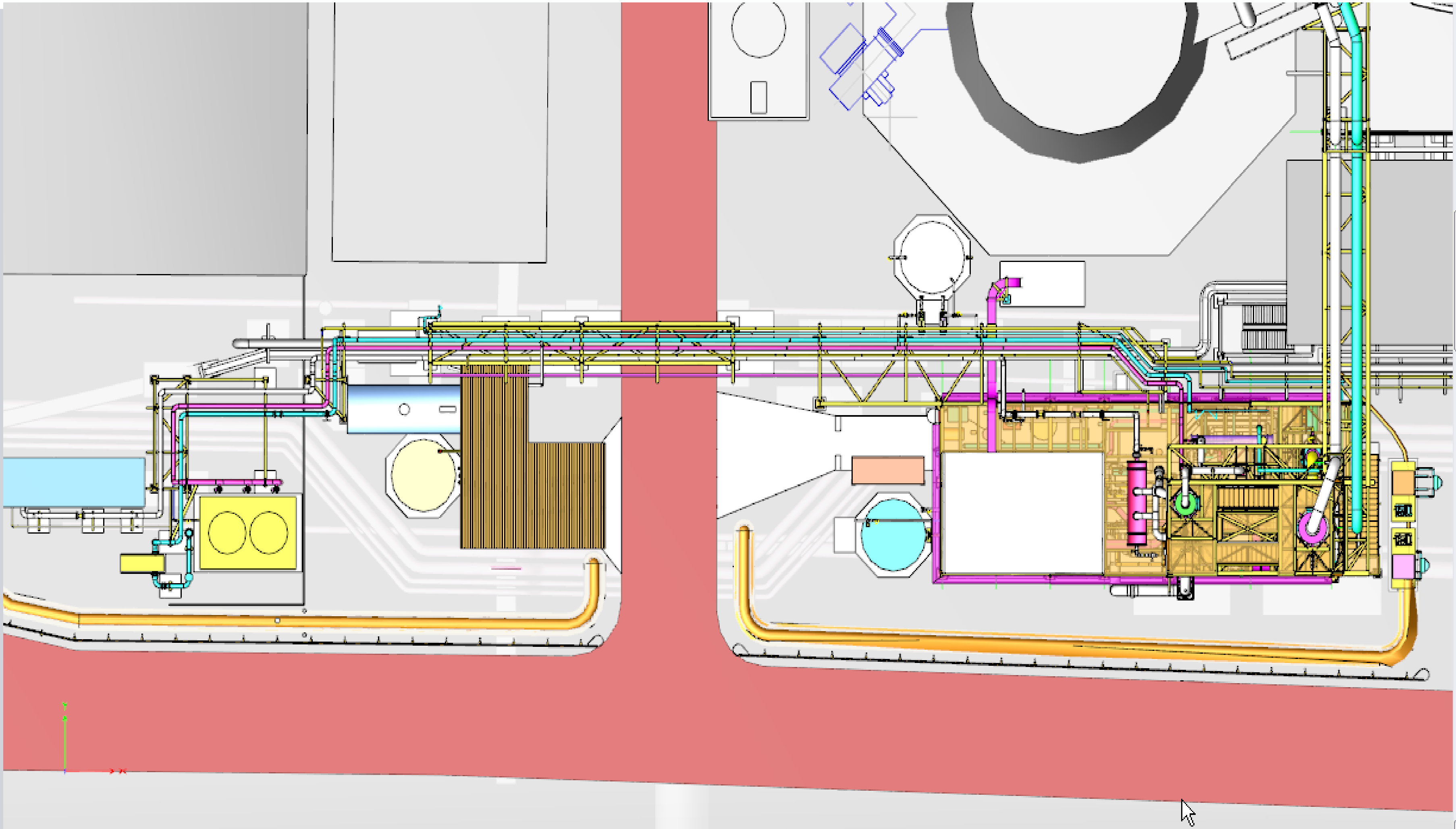
SIEMENS

Current Model Views

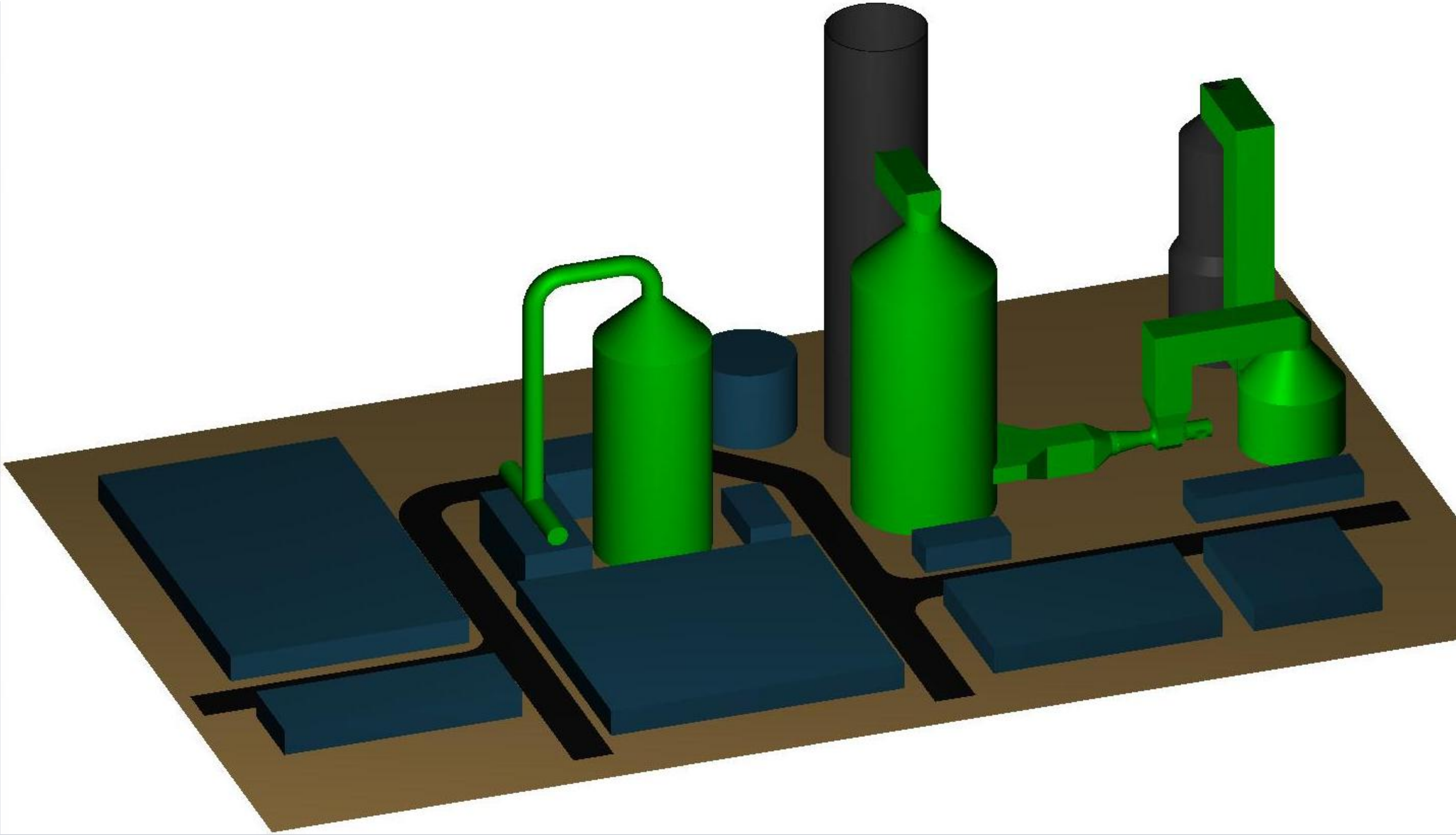
Current Model Views



Current Model Views – Plan at Grade



Techno-economic Study of PostCap Application
550 MW Utility Plant Case - Model



Industrial Applications

- Cement Production
- Iron and Steel
- IGCC

SIEMENS

Disclaimer

Disclaimer. This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference here into any specific commercial product, process, or service by tradename, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Acknowledgement. This material is based up on work supported by the Department of Energy, National Energy Technology Laboratory under Award Number DE-FE0003714.